Calgary's Airport Trail Tunnel - a Project Management Success Story

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Abstract

The Airport Trail Tunnel (ATT) is a 620-metre (m)-long, two-cell roadway tunnel constructed underneath the Calgary International Airport's new runway and three taxiways that are currently under construction. Part of a 1.3-kilometre (km) section of roadway being constructed to provide better network connectivity around the airport, the ATT has three lanes in each direction. The traffic forecast at the 20-year horizon estimates a volume of 27,000 vehicles per day. The ATT project was approved by The City of Calgary City Council (the Council) on February 7, 2011.

The ATT was designed to meet the National Fire Prevention Association's (NFPA) Code 502, "Standard for Road Tunnels, Bridges, and Other Limited Access Highways." As a result, many ancillary systems are required to support fire occupant safety. These include smoke and noxious gas ventilation using 32 jet fans, a stormwater pumping station and reservoir, a fire alarm system with heat and smoke detection, a dry stand pipe system to assist in fire-fighting, emergency radio signal boosting, tunnel illumination, and power redundancy using power supplied from both ends of the ATT.

Because the project was approved less than 19 months before significant portions needed to be installed and backfilled for construction of the runway above the ATT, the schedule was a primary focus for the work. About half of the tunnel was built and backfilled in less than 8 months to meet this schedule. The remaining structure was completed in the 4 months that followed, with turnover of about 90 percent of the ATT to the runway project 2 months after that.

To facilitate the accelerated schedule, the work was issued for tender in pieces as the design was brought to a stage where it could be tendered. Since a total of 15 major tender packages were tendered, each with as many subcontracts in them, management of the project required close attention to the overlaps and omissions among the scopes of work in these tender packages.

This paper, "Calgary's Airport Trail Tunnel - a Project Management Success Story," by Andrew Boucher, Senior Project Manager, CH2M HILL and Joost Bolderheij, Principal Manager, CH2M HILL, will discuss the design and construction of the ATT, as well as the project management challenges encountered.

Introduction

Flying into Calgary currently involves landing on one of two runways at angles to each other, which can be used simultaneously only under reasonable wind conditions. To increase the landing and take-off capacity of the airport, a second runway has been constructed, parallel to the existing north-south oriented runway. To increase the capacity of the airport to handle more passengers and aircraft movements, the Airport Development Program (ADP) includes an expansion to the existing terminal, as well as the Runway Development Program (RDP). The new runway will be significantly longer than the existing one at 4,367 m to allow landing of the world's largest aircraft (the Airbus A380 and the Boeing 747-800) and will facilitate an increase in international air traffic to the airport.

One of the significant access routes to the airport was via Barlow Trail. The RDP necessitated closure of Barlow Trail between McKnight Boulevard and Airport Trail. Although Metis Trail was developed to replace Barlow Trail as a major north-south route, it does not currently have a connection to the airport. The ATT will run under the new runway and will extend Airport Trail from Barlow Trail to 36 Street northeast (NE). This extension of Airport Trail would not only provide another access to the airport, but will also be one of the main east-west connectors in Calgary. Future connection of Airport Trail to Metis Trail and the Calgary Ring Road (further east) is under discussion between the Calgary Airport Authority (also referred to by Calgary's international airport code of YYC) and The City of Calgary (The City). The YYC is one of the largest employment centres in Calgary. The ATT will provide a new access for employees, the residents of future developments north and east of the airport, and the flying public. The ATT cross section was also set to accommodate light rail transit (LRT) in the future.

The runway has been in the YYC master plan since the 1970s and the ATT has been considered in The City's planning since at least 1995. YYC's construction schedule of the new runway accelerated the construction of the ATT. It is much easier and less expensive to construct a "cut-and-cover" tunnel rather than boring a tunnel under an active runway at a future date. In November 2010, the Council approved a study on the ATT to estimate the cost to construct a tunnel under the new runway. The estimated cost for the construction of this tunnel was $294.8 million, which was approved by the Council in February 2011. Although the ATT is owned by The City, it is located in/on lands leased and maintained by YYC and owned by the Government of Canada. The agreement with YYC for the land sublease was completed late in June 2011. Construction started in July 2011 with bulk excavation. The ATT is expected to be open for public use in May 2014.

General

The ATT is a 620-m-long, two-cell roadway tunnel constructed underneath the YYC's new runway and three taxiways, as shown in Figures 1 and 1B. Part of a 1.3-km section of roadway (between Barlow Trail and 36 Street NE) being constructed to provide better network connectivity around the airport, the ATT has three lanes in each direction. As shown in Figure 2, lane arrangements for opening day and for potential future LRT are laid out with two separated cells for east and west-bound traffic. Figure 3 is a rendering of the completed structure, as viewed from outside the west portal. Figure 3B is a photo of a similar view today.

Construction of the ATT was managed by PCL-Parsons-Dufferin (PPD), a joint venture, who was also the construction manager for the RDP (a factor in their selection for the ATT). CH2M HILL was the lead consultant for the ATT with significant work from Associated Engineering (AE) and Thurber Engineering. CH2M HILL also had a consulting role in the runway, as a subconsultant to AE. Structural engineering and site resident engineering services, including contract administration and quality assurance for the ATT, was provided by CH2M HILL. AE provided engineering for roadway, drainage, electrical, and mechanical works as well as structural engineering for the stormwater lift-station structure. Thurber Engineering was the geotechnical and materials subconsultant.

To meet the tight timelines imposed by the RDP schedule, the ATT was broken down into 15 work packages. Work packages were publicly tendered, and were generated as the design progressed, or where long-lead equipment was identified. This allowed portions of the construction to proceed before all design was completed, and to start production on long-lead items such as fans and electrical equipment.

The ATT structure consists of a cast-in-place, conventionally reinforced, concrete rigid frame on strip footings constructed with a cut-and-cover construction method. Figure 4 shows a typical cross section of the structure, and Figure 5 is an elevation of the portal walls (concrete retaining walls) at the ends of the tunnel. For construction, the tunnel was divided into 50 segments along the length. The walls and roof were monolithically cast in 12.5 m sections using a steel formwork system of lead and infill (even numbered) segments. Odd numbered segments (called lead segments) were cast first and then followed with infill segments. Casting started from the middle of tunnel, progressing to both ends. Four sets of steel forms were used and two engineered tents were fabricated for heating and hording (or shading and blocking wind) and improving the concrete curing conditions (see Figure 6). Both the formwork and tents were mounted on rails to allow them to be moved along the length of tunnel during construction. The main structure was constructed between February and October 2012 (footings were constructed from November 2011 to August 2012). A total of more than 65,000 cubic metres of concrete was cast using more than 12,000 tonnes of reinforcing steel for the ATT structure. A stormwater sewer system and watermain piping were installed below the ATT to provide stormwater drainage and firefighting water supply. Figure 7 shows a picture during construction in May 2012, indicating the white hoarding tents, lead formwork in place, and the runway and taxiway grading.

Life Safety

Safety for people inside the ATT structure was high priority and the air quality in the tunnel was the paramount factor. Facilitating the exhaust of noxious gasses, and smoke in the case of a fire, was very important. A system of sampling tubes was installed in the ATT, which provides for air sampling to be conveyed to eight locations in the tunnel. A cabinet at these locations houses smoke and gas detection equipment connected to the sampling tubes, and a vacuum pump that constantly draws air from the tunnel. This system has a proprietary name of VESDA (Very Early Smoke Detection Apparatus). This was to meet NFPA Code 502, “Standard for Road Tunnels, Bridges, and Other Limited Access Highways.” Upon the detection of smoke or noxious gas, 32 100-horsepower jet fans located throughout the tunnel (with four sets of four fans in each cell of the tunnel) are turned on. Noxious gasses are exhausted with traffic in the cell of the tunnel where they are detected, using less than half of the fans. Smoke is evacuated using all the fans in the tunnel, and are automated to blow in the direction of traffic in the cell the smoke is detected (fans in other cell blow in reverse). This was set up to eliminate the cycling of smoke from the affected cell into the “clean cell.” This will also allow firefighters to get as close as possible to the source of the smoke (presumably a fire). The fans are 5.6 m long by 1.1 m in diameter and weigh approximately 570 kg each. They are designed to work at temperatures up to 250ºC for 1 hour.

In a manner usually seen in high-rise buildings, the ATT has an emergency system consisting of a networked fire alarm system with manual pull stations located at each portal, each hose station, and each inter-tunnel door. Fire extinguishers are co-located with the fire alarm pull stations at 75 m spacing along both carriageways. A linear fibre optic heat detection system and the VESDA smoke detection system monitor the ATT and are connected to the fire alarm panels in each control building (located at the east and west portals to the tunnel structure).

Firefighters responding to an incident at the ATT will access the fire alarm control panel from either control room at the ends of the tunnel. Adjacent to the fire alarm panel is access to the public address system and emergency phone system in the tunnel. Emergency personnel also have access to 24 camera feeds from the tunnel, displayed on monitors above the fire alarm panels. Most importantly, access to manual control of the fans is co-located in this area. The manual fan control system has a display indicating each fan's operation status (direction and power), as well as visual representation of smoke, gas detection, and emergency phone operation. In the tunnel, a radio repeater system for first responders (emergency personnel) provides use of the city-wide emergency responder radio system. Both carriageways are equipped with a dry stand pipe, which has fire department hose connections every 75 m. This system requires the standpipes to be charged with water pumped from hydrants located outside each portal, allowing real time adjustment to water flow and pressure.

To provide ongoing operational oversight, The City of Calgary Transportation Department's Roads Business Unit elected to provide remote monitoring of all aspects of operational safety at the ATT. CCTV feeds, electrical equipment alarms, fire alarm status, smoke and gas detection, and traffic monitoring are all relayed to The City's Traffic Operations Centre (TOC). The City uses the TOC to monitor its network of traffic cameras, monitor and operate lane reversal systems, and operate The City's traffic signals network. A wall of television monitors installed at the TOC allows operators to view any of the tunnel cameras, among the other traffic cameras available for use. The software interface used at the TOC to execute lane reversal signage, and incident detection, has been modified to include a prompt when issues arise at the ATT.

Power and Lighting

Provision of redundancy in electrical power supply for emergency systems was also a factor in electrical system design. Instead of using diesel-based power generation as backup, electricity for the project is provided from two separate electrical grid substations. This eliminated significant capital and operational costs, as well as the fire hazards associated with petroleum onsite (something not supported by YYC). To complete the redundancy, a pair of transfer switches are installed in each control building. To keep the power transfer smooth, a 400 kilowatt (kW) uninterrupted power supply (UPS) is also installed in each control building. Under normal conditions, power is supplied to each half of the ATT from each power source. If one electrical source fails, all of the ATT power requirements will be supplied by the second source through an automatic transfer of power.

The ATT is lit by 1,376 high pressure sodium fixtures. Because the physiological adaptation of human eyes to darkness is significantly slower than it is to brightness, more light is required in the tunnel in daytime than at night. As a result, significant extra lighting has been provided at the entrances to the tunnel (more than 85 percent of the fixtures). The nighttime lighting fixtures have dedicated, un-switched power for emergency lighting. Although all lighting power is backed up by UPS, in the event of a total (city or area wide) power failure; lighting, life safety, and controls would function for at least 15 minutes.

Storm and Ground Water

Removal of water was required because the ATT created a large depression in the natural landscape that naturally collects water. The use of a conventional roadside gravity drainage system was implemented to collect stormwater. Consideration to connect to offsite sewer systems was made, but the systems were not close enough to the ATT to justify the significant trenching length and depth required to drain the ATT. A lift station, with an associated 1,000-cubic-metre surge tank, was built to accommodate water collected at this site. A construction photo of the stormwater tank is included in Figure 8. To prevent groundwater-related erosion at the portals, and minimize hydrostatic loading of the ATT structure, a perforated pipe, surrounded by free draining rock, was installed at both toes of each wall foundation, draining into the storm sewer piping in the ATT. The longitudinal road profile required to pass beneath the new airfield facilities imposed a low point in the roadway about 80 m inside the west portal. This led to a consequential location of the lift station outside the west portal of the ATT.

Structure

The ATT structure consists of a cast-in-place reinforced concrete two-span rigid frame on three strip footings with two clear spans of 16.3 m each and a total length of 620 m (see Figure 4). As the soil structure at site mainly consisted of 2.5 to 4 m of clay till overlying bed rock (claystone, siltstone, and sandstone), a significant portion of the project excavation was in rock. The top of the structure was mainly below the top of the bed rock level, and depending on the location along the length of the tunnel, backfill was either a free-draining, graded granular material, or native material with a free draining gravel layer adjacent the structure. Sections of the ATT below airfield paved structures were built with approach slabs to minimize differential settlement. Tunnel portals at both ends consist of cast-in-place reinforced concrete retaining walls (see Figure 5).

Structural analysis and design of the ATT was based on the Canadian Highway Bridge Design Code (CHBDC). Other references were also used for aircraft loading, including the Federal Aviation Administration's *Airport Pavement Design and Evaluation (Design of Structures for Heavy Airplanes)* and the American Concrete Institute's *Airport Runway Bridge Loads*. Although not the heaviest plane (some military aircraft are heavier), the Airbus A380 has a more severe concentration of loading under its landing gear, and thus was the main design loading used (other landing gear configurations also impacted design loading conditions). Aircraft loading was applied to the whole length of tunnel to consider the possibility of any future developments, and errant aircraft.

To accommodate concrete curing behaviour, construction joints were created at 12.5-m spacing (to coincide with formwork length) along the length of the tunnel to allow for minor concrete movement. Every third or fourth joint was modified to act as a movement joint. All joints provided transfer of loading from outside the tunnel (soil and airfield live loading).

Durability

Replacement of sections of this structure would likely involve closure of the airfield, so durability of the structure was a major consideration in this project. Because it is expected that the drainage systems will keep the inside of the tunnel mainly dry, high performance concrete and galvanized steel were only used in the splash zones of portal walls and in the first two segments of the ATT in from the portals at each end.

Crack control requirements dictated much of the concrete design. A concrete mix with a high fly-ash content was used to minimize the early curing shrinkage and the rate of heat of hydration generated. All exposed concrete has an elastomeric coating (pigmented sealer) applied to it. The outside face of the tunnel walls and roof slabs are protected by waterproofing. The selected system consisted of a "Volclay" sheet and a protection layer, both mechanically attached to the concrete (see Figure 10). This system helped meet the project schedule, because it had the advantage of not being sensitive to temperature, humidity, or the curing state of the concrete and therefore could be applied shortly after removing the forms.

Fire Protection

Although analogies to building structures could be made in terms of the fire rating of the ATT structure, the type of fire anticipated for a roadway tunnel is significantly hotter, burns faster, and has the potential to last longer than those seen in most building fires. The underside of roof slabs are covered by a layer of fire protection. The applied fire protection system is a cementitious type, and was required to keep the roof concrete temperature low enough to prevent explosive spalling of concrete from moisture in the concrete flashing to steam. Both the roof and wall concrete was also protected from reaching temperatures that would compromise the reinforcing steel in the concrete, by providing sufficient concrete cover over the first layer of steel.

Project Management Challenges

Tight Schedule

Meeting the tight schedule was arguably the main challenge of the project and affected many decisions made during the design and construction process. The project team began to be assembled in late winter 2011, but did not get full approval to proceed with work until summer 2011. Design did commence during this period, but under a cloud of uncertainty. Given that, from the time excavation started, to the first contractual obligation was only 15 months, the main focus was constructing the structure. With incomplete design parameters, and ongoing interaction with the runway project, the best information at the time was used to proceed with excavation (the first work package).

To help stack tasks, so that concurrent work could be completed efficiently, another 14 work packages were issued, as project design decisions became available. The next work package started work on the site drainage and water supply, installing these utilities below the roadway in the tunnel. The next piece to be started was the ATT structure, including formwork, reinforcing, embedded electrical conduit and boxes, and concrete placement. With this large piece of the project underway, the construction management and project management teams focussed on long-lead items like the exhaust fans (needed to be proofed through a 1-hour elevated temperature performance test), the electrical substation equipment (from multiple suppliers across north and central America), and the control buildings (custom built to have all electrical controls pre-installed).

In the early part of 2012, the protective elements of the concrete were tendered; fire proofing, waterproofing, and the pigmented sealer for exposed concrete surfaces was completed. The next piece to be completed was the backfill of the structure so that the runway construction over the tunnel could continue. This work, including some pile installation at the runway approach slabs, and further grading of the approach roadways was started in the summer of 2012. With the installation of the control buildings slated in early 2013, electrical and mechanical completion of the project was tendered. An additional scope was tendered separately, because of the specialist nature of the work for the programming and supply of the programmable logic controllers (PLCs). The PLCs are computers that control the automated aspects of the ATT, such as fans, lights, and life safety systems. This work proved to be key in that the independent contract helped coordinate what had become a fractured design process.

Although many of the previous work packages were tendered to encourage multiple contracts, for various scopes within each package, this last package was seen as more conventional road work, which is usually let to a general contractor. The contracting for the final completion work through one entity had its challenges for this project, as roads projects do not often have the schedule restrictions that had become the norm for this project. By the end of the project, communication directly to subcontractors of the general contractor had become an everyday occurrence.

Though not a schedule issue directly, the procurement method used to engage contractors meant we were obliged to use the lowest compliant bid for each work package. One of the contractors that was selected for the project was not familiar with the Calgary market or construction working culture. This affected morale on the project, and led to far more focus on contractual issues than the issues that needed attention to meet schedule. In hindsight, more focus on engaging contractors with familiarity to the city and its work culture would have helped the project progress more effectively.

Budget

Budget constraint was also a factor in this project, as the team had to follow The City's purchasing regulations, which set out the need to tender the vast majority of the work. Although this was mostly a matter of significant administration costs, the project financial decisions have been meticulously recorded as a result.

Because of the multiple work packages this project required, one challenge with this style of procurement led to the separation of conduit installation and the installation of cable into the conduits. Although the low bidder on the second scope of work (cable installation) was low by a significant amount, the resolution of their ongoing technical difficulties were stymied by this contractor's choice to try and recoup costs before resolving issues.

Communication

Communication with the project team for the ATT flowed easily between levels of people working on the project. Although formal documentation often had to be made afterwards, the information required to make decisions was sought and provided efficiently at first to keep the schedule moving forward. Though meetings were often long and full of digressions, frequent meetings meant that issues were addressed and decisions were made quickly. The Owner's motivation to bring this project to reality on time also helped move decisions to quicker resolution. The City had multiple events held onsite to recognize the efforts of all people involved with the project, and this also encouraged communication between all parties on the project.

The organizational structure for this project also had an advantage in that the Construction Manager and the Consulting Team both worked towards meeting the schedule set by the owner. Both entities had differing interests in the decisions to be made for the project, from quality and schedule perspectives, but the open dialog with the owner about costs and time made resolving issues much more transparent.

Technical Issues and Innovations

Many issues arose in this large scale project, some of them are highlighted below.

A relatively short time from placing of concrete to removal of the formwork was required for the casting of the concrete segments of the tunnel. Although other schemes were considered, a 3-day period was used, without the implementation of shoring after removal of the formwork. This required an initial rapid rise of concrete strength, which brought with it a significant heat of hydration challenge. This was managed with a revised mix design that maximized the use of fly ash, which meant additional testing and proofing of the mix before it could be implemented for use. Additionally, the permitted maximum concrete temperatures had been more stringent than many codes suggest, and a relaxation of this requirement also contributed in the resolution to this issue. Although ice was used extensively to cool the ATT concrete while it was being batched, the significant volumes of ice required for the 850-cubic-metre concrete castings meant that a further cooling measure needed to be pursued to maintain a reasonable rate of concrete production. While waiting for approval of the revised mix design, a liquid nitrogen injection system was also mobilized for use on the hotter days of July. This was a mixed success, as the hardware involved was best set up for one type of ready-mix truck, and resulted in some damage to the mixing fins of trucks of a different geometry.

The first excavation contract for the project was let to the excavator working on the runway project, and this meant mixed results for the ATT. They brought an innovative method to the table, with the use of "terrain leveller" machines that broke rock into smaller pieces that could be used as fill on the runway project. Unfortunately, this method took longer than anticipated because of the varied geology of the material to be excavated. As seen with the second excavation contractor, a process of ripping and breaking the rock would have been much faster. Although it may have resulted in a more predictable schedule, assigning means and methods to a contract at tender time would likely have resulted in significantly larger tender costs.

Commissioning of the electrical and mechanical systems was challenging as it was broken into multiple scopes and responsibilities. To recognize this challenge, the owner brought in a member of their organization who had worked on similar systems for the recently completed west LRT in Calgary. The additional modification to offsite facilities to enable remote monitoring was a significant scope in the end of the schedule for this project. The tunnel CCTV and fire alarm are monitored offsite, and getting the multiple monitoring locations up and running proved to be almost a separate project. About 3 weeks before opening, a full-scale smoke test was conducted to prove the alarm and monitoring systems; this test went very well and resulted in confirmation of much of the alarm monitoring systems. Some photos of this event are shown in Figure 12.

The installation of conduit into the concrete structure (see Figure 11) occurred at a time when the design was not complete. As design progressed, the cables and wires required to service the design changed, and in some cases approached the code maximum ratio between total cable area and conduit area. To manage this challenge, revisions to supplied voltage, and wire type were made after cable pulling had commenced. Additionally, the transition between the tunnel and portal walls was a technical challenge for the installation of the conduits. This challenge led to some need to direct how cables were to be installed into some conduits too.

As part of the multi-party procurement, the control building supply occurred separate from both the conduit installation and the cabling work. This presented a challenge with connection of the three contracts, but was managed on an issue-by-issue basis that was often challenging. As one positive outcome, construction of the control buildings offsite meant a less congested project site, and meant that the buildings were started before the foundation area was even available for construction. Installation of the west control building is shown in Figure 13.

Conclusions

The ATT is planned to open to traffic on May 25, 2014. Runway project turnover deadlines for August 31 and October 31, 2012, were successfully met on time and on budget and the portions of the structure under the runway and taxiways were handed over to YYC to continue their construction of the RDP. The runway is scheduled to go into service in June 2014.

This success was only possible because of close collaboration between the design and construction teams and the owner. All of the parties involved met weekly to discuss all the issues regarding design and construction and solve problems. The project had many challenges but all of those were discussed and actions were taken to overcome them. When the deadlines were set they seemed unrealistic and completing and backfilling the main structure of a 620 m tunnel in less than 10 months seemed unachievable. It has been a great achievement for all of those involved in this project and an accomplishment to be proud of.

Acknowledgements

Although not a complete list of those that contributed to construction of this monumental Calgary project, the following were invaluable

- The City of Calgary: owner and operator
- CH2M HILL: project management, structural engineering, and site resident engineering services
- Associated Engineering: roads, drainage, mechanical, and electrical engineering
- PPD (PCL, Parsons, Dufferin) Joint Venture: construction management
- Thurber Engineering: geotechnical engineering

Figures

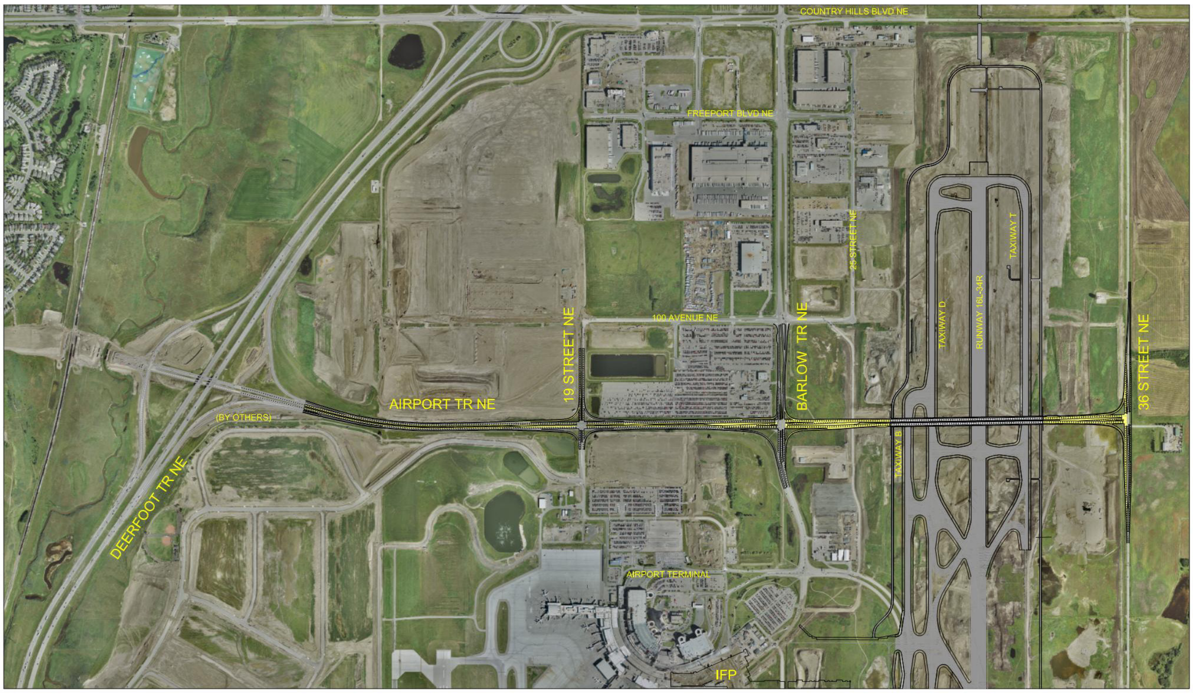

FIGURE 1 – TUNNEL LOCATION IN RELATION TO ROAD NETWORK (NORTH IS UP)

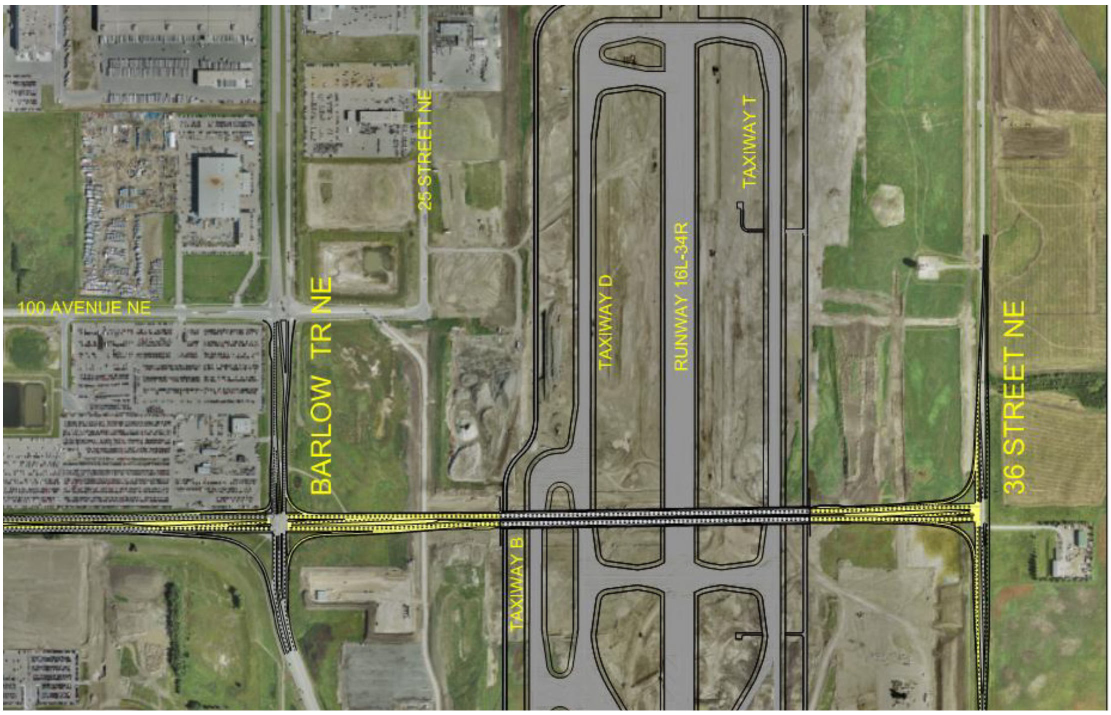

FIGURE 1B – TUNNEL LAYOUT UNDER THE RUNWAY AND TAXIWAYS (NORTH IS UP, AIRPORT TRAIL RUNS EAST WEST)

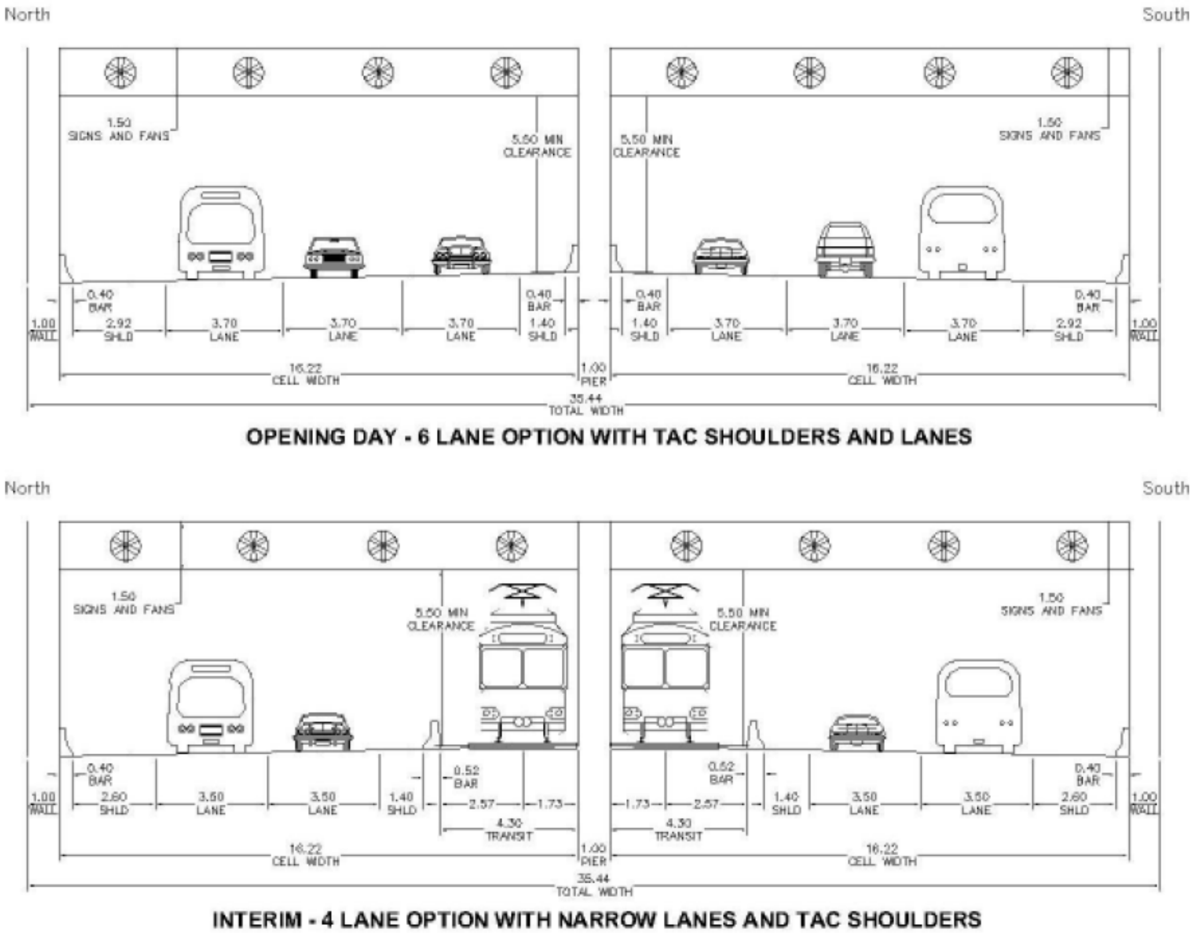

FIGURE 2 – ATT FUNCTIONALLY PLANNED LANE ARRANGEMENT

FIGURE 3 – RENDERING OF COMPLETED STRUCTURE FROM OUTSIDE OF PORTAL

FIGURE 3B – VIEW OF THE TUNNEL LOOKING WEST FROM 36 STREET

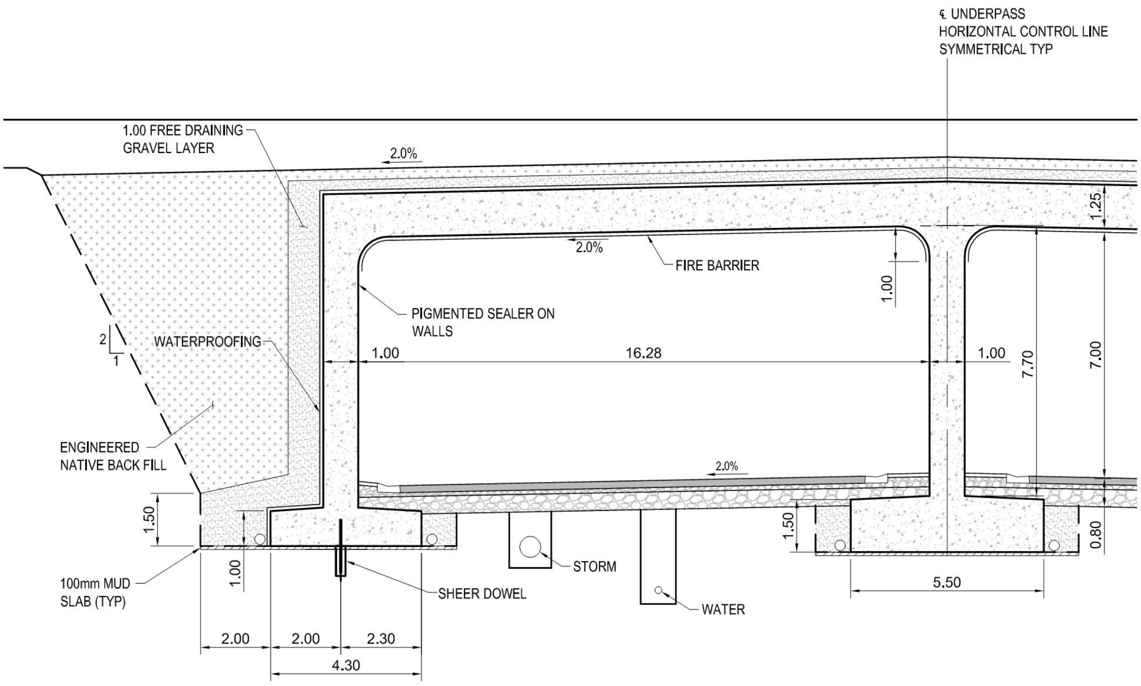

FIGURE 4 – TYPICAL SECTION OF TUNNEL WITHOUT APPROACH SLAB, AREAS AWAY FROM TAXIWAYS AND RUNWAY

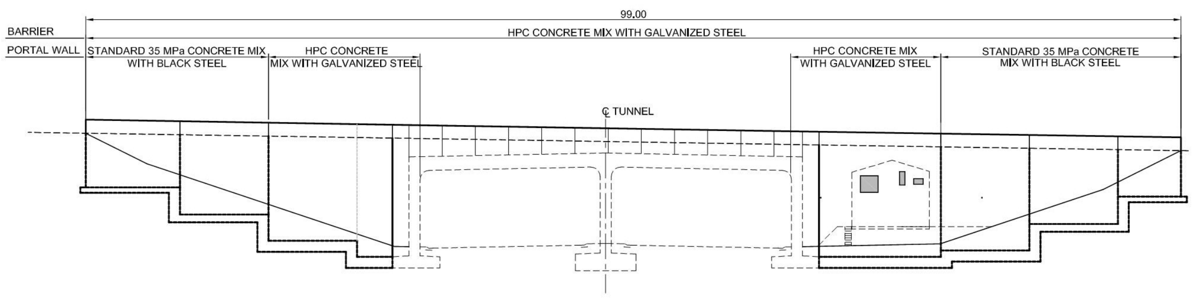

FIGURE 5 – ELEVATION OF TUNNEL PORTAL, SHOWING STEPPED FOOTINGS AND CONTROL BUILDING

FIGURE 6 – STEEL FORMWORK AND HORDING TENT USED FOR TUNNEL CONCRETE CASTING

FIGURE 7 – TUNNEL STRUCTURE DURING CONSTRUCTION, MAY 2012, NORTH IS UPWARDS

FIGURE 8 – STORMWATER LIFT STATION UNDER CONSTRUCTION – NOTE DEPTH OF EXCAVATION

FIGURE 9 – SECTION OF TUNNEL SHOWING A MOVEMENT JOINT

FIGURE 10 – STEPPED INSTALLATION OF TUNNEL WATERPROOFING SYSTEM AND BACKFILL

FIGURE 11 – AREA OF HIGH CONDUIT DENSITY IN TUNNEL WALL

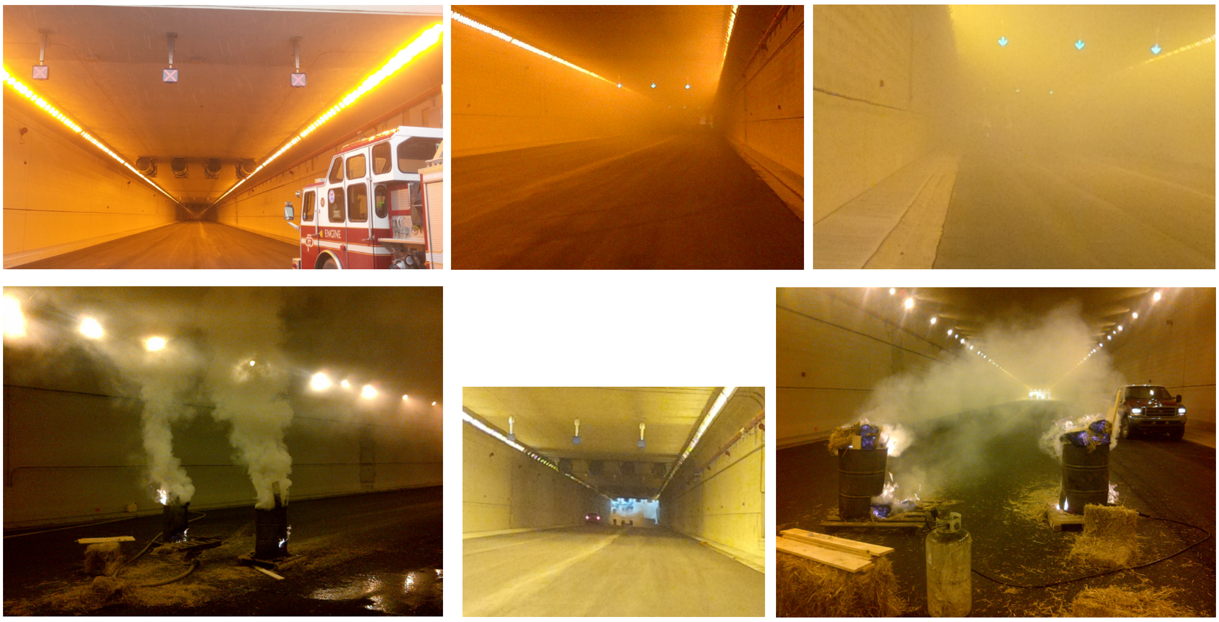

FIGURE 12 – PHOTOS OF TUNNEL SMOKE TESTING

FIGURE 13 – USING CRANES TO INSTALL THE WEST CONTROL BUILDING